Fostering the replication of smart sand storage dams in arid and semi-arid areas:

Practical recommendations to minimise siltation, seepage, evaporation and construction costs.

Advanced technical training course for practitioners
Kitui, Kenya
3rd February 2017

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Hamburg University of Technology, Germany

Acknowledgements and citation

- These training materials are based on innovative practical recommendations for the siting, design and construction of sand storage dams which form part of the PhD research on March 2017 of Josep de Trincheria.

- These training materials also contain know-how and experiences of Erik Nissen-Petersen and his extensive work for more than 50 years on rural water supply in arid and semi-arid areas of sub-Saharan Africa with ASAL Consultants Ltd. To his efforts and insightful observations, we all practitioners who have learnt from his work, are most grateful.

- These materials should be cited as it follows:

De Trincheria, J. (2017). Fostering the replication of smart sand storage dams in arid and semi-arid areas: Practical recommendations to minimise siltation, seepage, evaporation and construction costs. Advanced technical training course for practitioners on siting, design and construction of smart sand storage dams and their link with roadwater harvesting, Kitui, Kenya, 3rd February 2017. Roads for Water Consortium, MetaMeta, Wageningen, the Netherlands.

Goal

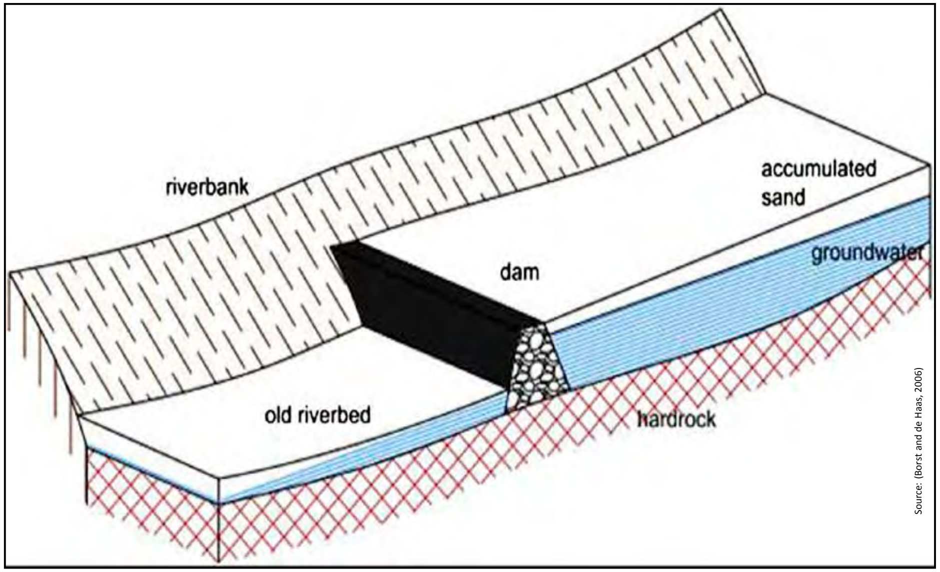
To showcase practical recommendations that can facilitate the replication of “smart sand storage dams” in arid and semi-arid areas, i.e.:

- Systematic optimal performance and cost-efficiency levels in different hydrogeological environments.
- Robustness to siltation, evaporation and seepage.
- Robustness to variability of rainfall, runoff and sediment transport.
- Minimisation of construction costs.
- Higher lifespan and robustness to floods.

This presentation

1. What is a SD?
2. What is siltation?
3. Why SDs are vulnerable to siltation?
4. How does siltation affect SDs?
5. How many silted-up SDs are out there?
6. Investment on silted-up SDs
7. Minimising siltation
8. Minimising seepage losses
9. Minimising evaporation losses
10. Construction recommendations
11. Restoration of silted-up SDs

What is a sand storage dam?



- A sand reservoir which can continuously fulfil the water needs of beneficiaries during the entire dry season.
- An increase in the volume of sand sediments on the original riverbed.

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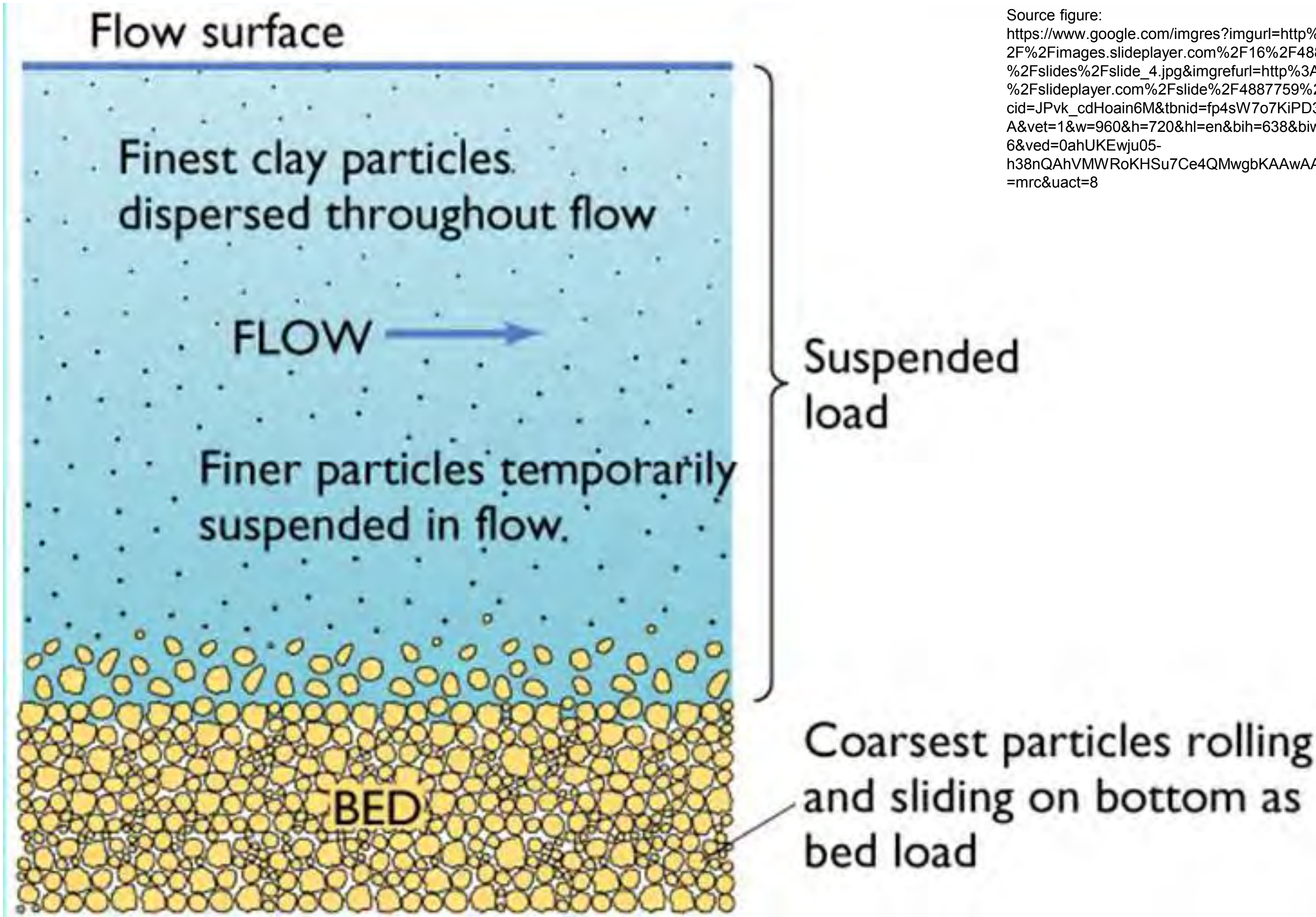
Hydrogeological working principle of a SD



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Click it!: https://www.geolsoc.org.uk/ks3/webdav/site/GSL/shared/Animations/Sediment%20animation.swf

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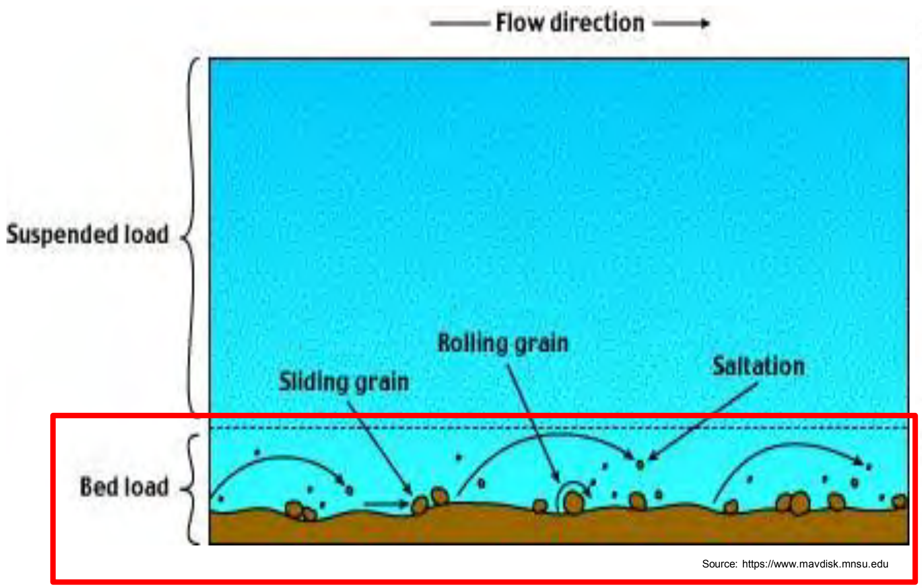

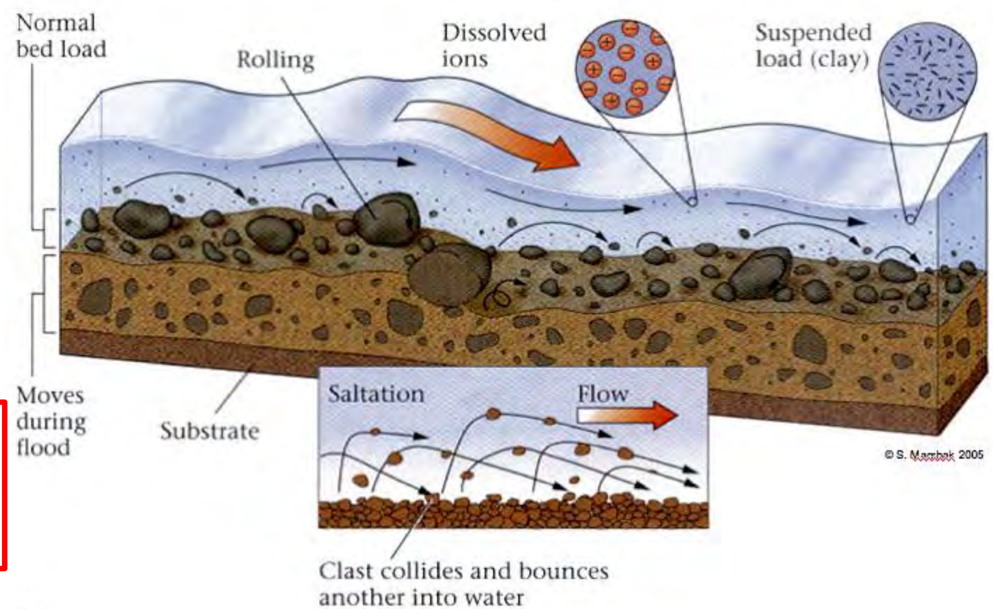

- Maximise coarse grain-size sediments of high permeability.
- Minimise fine grain-size sediments of low permeability.

→ Exclusive accumulation of the bedload transport.

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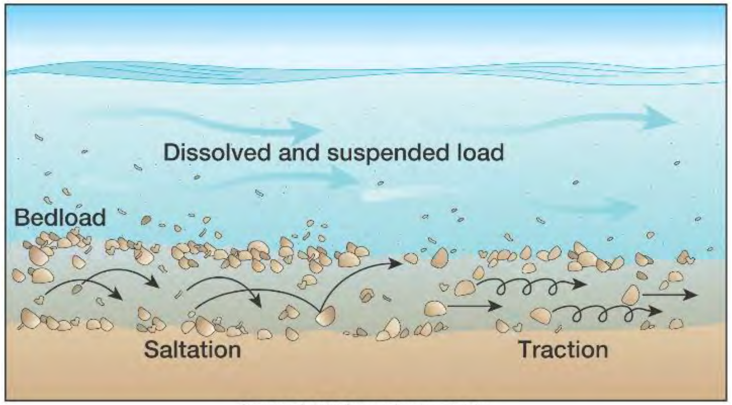
What is siltation?

- Siltation is the accumulation of large volumes of low-permeability fine grain-size sediments in the reservoir.

Picture: Josep de Trincheria

- Why? → The spillway blocks portions of the suspended load.



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Why are SDs vulnerable to siltation?

1. Height of the spillway increases fine grain-size sediment deposition.

2. The bedload transport is a minority component of the total sediment load in the runoff.

3. The bedload transport is highly variable both inter- and intra-annual variability, in spite of the geology of the site.

4. One-stage spillway does not take into account the 1-3 and it is widely replicated in Kenya

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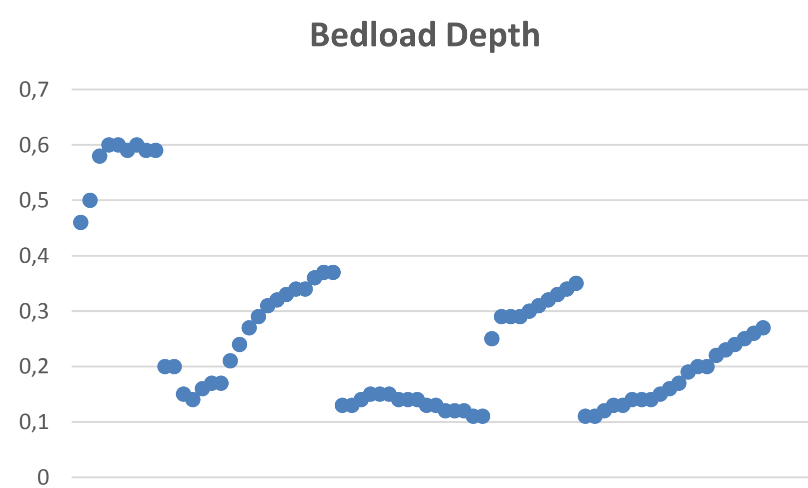
Bedload depth and variability

Table III. Channel-average bedload flux and hydraulic parameters for the ephemeral gravel-bed Nahal Yatir, northern Negev Desert

Date and time	Bedload (kg m^{-1} s^{-1})	Depth (m)	Hydraulic radius (m)	Water surface slope (%)	Discharge (m^3 s^{-1})	Shear stress N m^{-2})	Power (W m^{-2})
8/1/91 14:34	3·69	0·46	0·38	0·70	3·7	27·0	74·9
8/1/91 14:35	4·66	0·50	0·41	0·71	4·1	29·5	84·3
8/1/91 14:37	3·37	0·58	0·46	0·72	4·8	33·6	101·0
8/1/91 14:38	4·54	0·60	0·47	0·73	5·0	35·0	106·3
8/1/91 14:39	6·32	0·60	0·47	0·75	5·0	35·7	108·7
8/1/91 14:40	5·33	0·59	0·46	0·75	4·9	35·5	107·4
8/1/91 14:41	6·33	0·60	0·47	0·74	5·0	35·3	106·9
8/1/91 14:42	7·05	0·59	0·47	0·76	4·9	36·1	109·3
8/1/91 14:43	6·62	0·59	0·47	0·77	4·9	36·7	111·2
8/2/91 8:39	0·92	0·20	0·18	0·84	1·2	15·6	29·4
8/2/91 8:41	0·81	0·20	0·18	0·85	1·2	15·6	29·1
8/2/91 8:53	0·35	0·15	0·14	0·83	0·7	11·7	17·4
8/2/91 8:55	0·20	0·14	0·13	0·83	0·7	11·3	16·0
8/2/91 9:55	0·34	0·16	0·15	0·84	0·8	12·7	20·1
8/2/91 9:57	0·48	0·17	0·15	0·85	0·9	13·4	22·2
8/2/91 9:58	0·45	0·17	0·16	0·87	1·0	14·2	24·2
8/2/91 10:00	1·09	0·21	0·19	0·91	1·3	17·7	34·5
8/2/91 10:01	1·38	0·24	0·21	0·93	1·6	20·4	43·0
8/2/91 10:02	2·06	0·27	0·24	0·94	1·8	22·7	50·5
8/2/91 10:03	3·25	0·29	0·25	0·95	2·0	24·3	55·7
8/2/91 10:04	2·73	0·31	0·27	0·94	2·2	25·6	60·7
8/2/91 10:05	3·44	0·32	0·27	0·95	2·3	26·5	63·7
8/2/91 10:06	3·47	0·33	0·28	0·95	2·4	27·5	67·0
8/2/91 10:07	4·33	0·34	0·29	0·96	2·5	28·4	70·0
8/2/91 10:08	3·03	0·34	0·30	0·96	2·6	29·1	72·4
8/2/91 10:09	3·75	0·36	0·31	0·96	2·7	30·1	76·1
8/2/91 10:10	4·19	0·37	0·31	0·96	2·8	30·7	78·4
8/2/91 10:11	3·41	0·37	0·32	0·97	2·8	31·1	79·6
6/3/91 15:15	0·33	0·13	0·13	0·86	0·6	11·0	14·5
6/3/91 15:17	0·33	0·13	0·13	0·86	0·6	11·1	14·6
6/3/91 15:22	0·60	0·14	0·13	0·87	0·7	12·0	17·3
6/3/91 15:23	0·50	0·15	0·14	0·88	0·7	12·3	18·0
6/3/91 15:26	0·59	0·15	0·14	0·87	0·7	12·4	18·5
6/3/91 15:27	0·57	0·15	0·14	0·88	0·7	12·2	17·7
6/3/91 15:28	0·46	0·14	0·14	0·87	0·7	12·0	17·4
6/3/91 15:31	0·65	0·14	0·13	0·87	0·6	11·7	16·4
6/3/91 15:34	0·52	0·14	0·13	0·87	0·6	11·3	15·0
6/3/91 15:37	0·36	0·13	0·12	0·87	0·6	11·0	14·2
6/3/91 15:40	0·49	0·13	0·12	0·87	0·5	10·6	13·2
6/3/91 15:41	0·45	0·12	0·12	0·87	0·5	10·4	12·4
6/3/91 15:47	0·35	0·12	0·11	0·86	0·4	9·9	11·2
6/3/91 15:49	0·49	0·12	0·11	0·86	0·4	9·6	10·2
6/3/91 15:54	0·31	0·11	0·11	0·85	0·4	9·2	9·2
6/3/91 15:56	0·32	0·11	0·10	0·85	0·3	8·9	8·2
6/3/91 19:04	4·68	0·25	0·23	1·01	1·7	23·3	50·3
6/3/91 19:05	3·52	0·29	0·26	0·98	2·1	25·6	59·4
6/3/91 19:06	4·35	0·29	0·26	0·99	2·1	26·0	60·5
6/3/91 19:07	4·08	0·29	0·25	0·99	2·0	25·6	59·0
6/3/91 19:08	3·33	0·30	0·26	0·98	2·1	26·0	60·8
6/3/91 19:09	2·52	0·31	0·27	0·99	2·2	27·1	64·3
6/3/91 19:10	3·37	0·32	0·28	1·00	2·3	28·3	68·3
6/3/91 19:11	4·16	0·33	0·29	0·99	2·5	29·1	71·6
6/3/91 19:12	3·65	0·34	0·30	0·99	2·6	29·9	74·5
6/3/91 19:13	2·98	0·35	0·35	0·99	2·7	30·6	76·9
23/3/91 15:44	0·36	0·11	0·10	0·87	0·3	8·8	7·8

5 runoff events in 1991 for an ephemeral stream in the Negev Dessert:
- Maximum bedload height was 0.6 m.
- Minimum bedload height was 0.1 m.
- Bedload is variable between different runoff events and during the same runoff events.
- A spillway of 1 m would have accumulated 40% silty and clayey materials on the surface if we take the first. runoff event, which was the most intense (!)
- With all the other runoff events the spillway accumulated between 60%-90% suspended load.



Reid, I., Laronne, J. B. (1995). Bed load sediment transport in an ephemeral stream and a comparison with seasonal and perennial counterparts. *Water Resources Research*, *31*(3), 773-781.

How does siltation affect SDs?

1. Low volumes of sand accumulated.
2. Low permeability and specific yield.
3. Low water yield.
4. Low water supply capacity.
5. Low cost-efficiencies (i.e. EUR/m3 water; EUR/household supplied).
6. High vulnerability to evaporation.
7. Not bridging the dry season.

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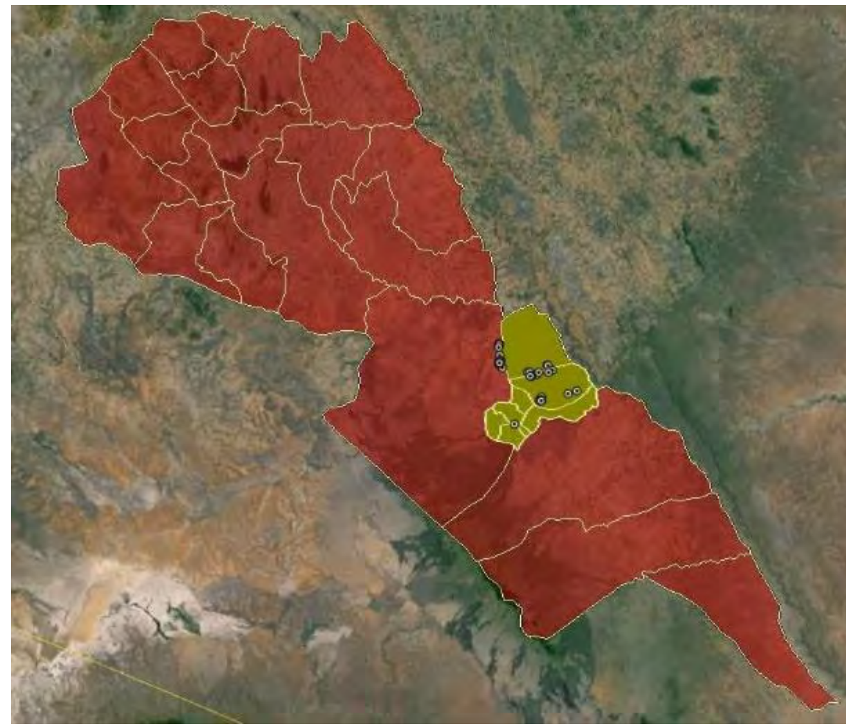
Study Area



De Trincheria, J., Leal Filho, W., Otterpohl, R. (2017). Towards achieving universal levels of optimal performance by minimising siltation in sand storage dams. Manuscript under review submitted for publication.

Methodology

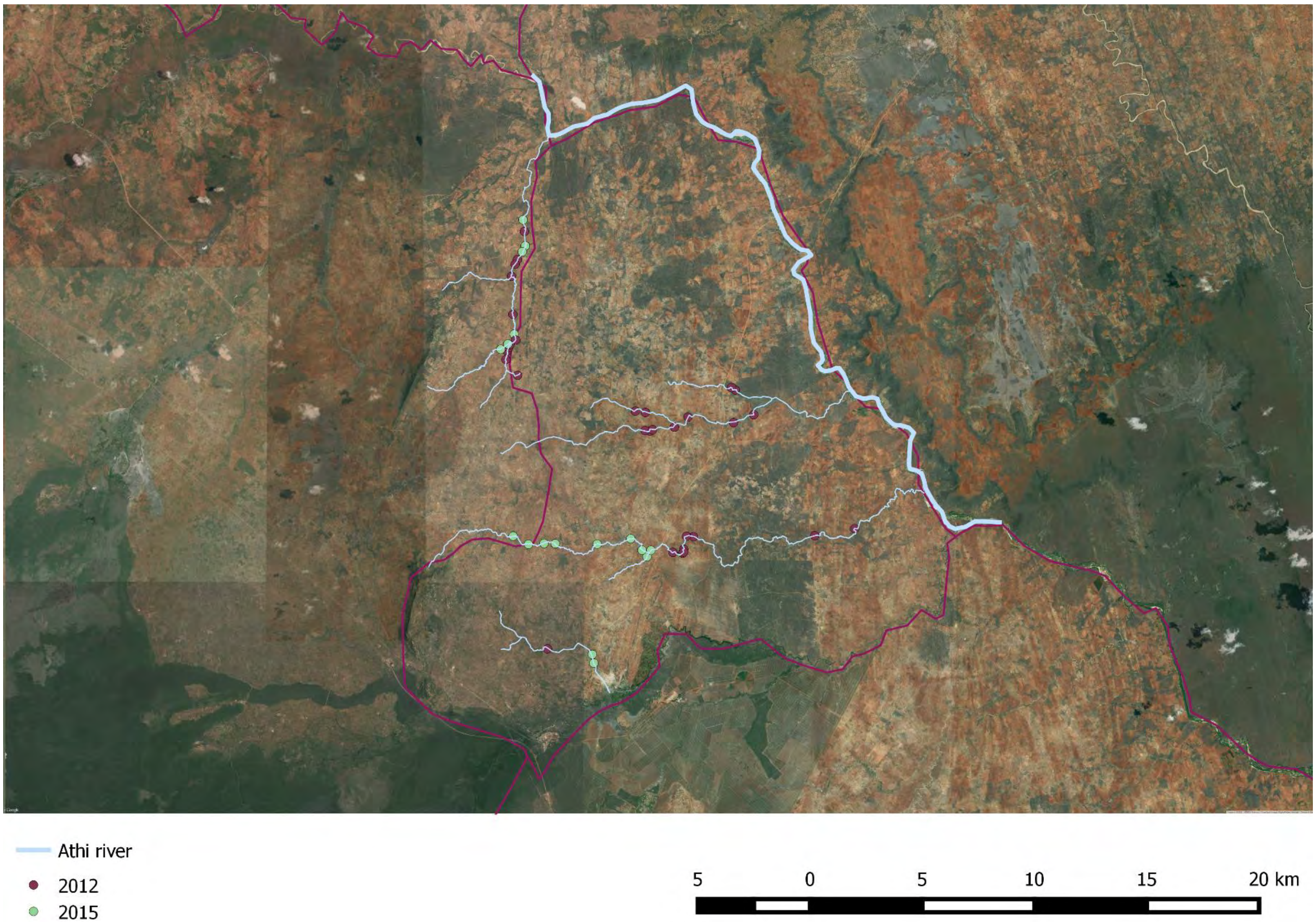
- **2012: 31 SDs evaluated**
  - On-the-ground physical survey
  - Analysis sand storage capacity; Yearly water yield; Supply capacity; Cost-Efficiency
  - Randomised semi-structured interviews with direct beneficiaries

De Trincheria, J., Nissen-Petersen, E., Leal Filho, W., Otterpohl R. (2015). Factors affecting the performance and cost-efficiency of sand storage dams in south-eastern Kenya [conference paper]. E-proceedings of the 36th IAHR World Congress, The Hague, the Netherlands, 28 June – 3 July, 2015.

- **2015: 48 SDs evaluated (incl. 2012's)**
  - Identification sediment texture
  - Spillway damage
  - Randomised semi-structured interviews with direct beneficiaries → water supply capacity during the dry season

De Trincheria, J., Nissen-Petersen, E. (2015). Sand Storage Dams: Performance, cost-efficiency, working principles and constraints. [conference presentation]. International Symposium on rainwater harvesting and resilience (ISRH), Dire Dawa, Ethiopia, 8th-12th June 2015.

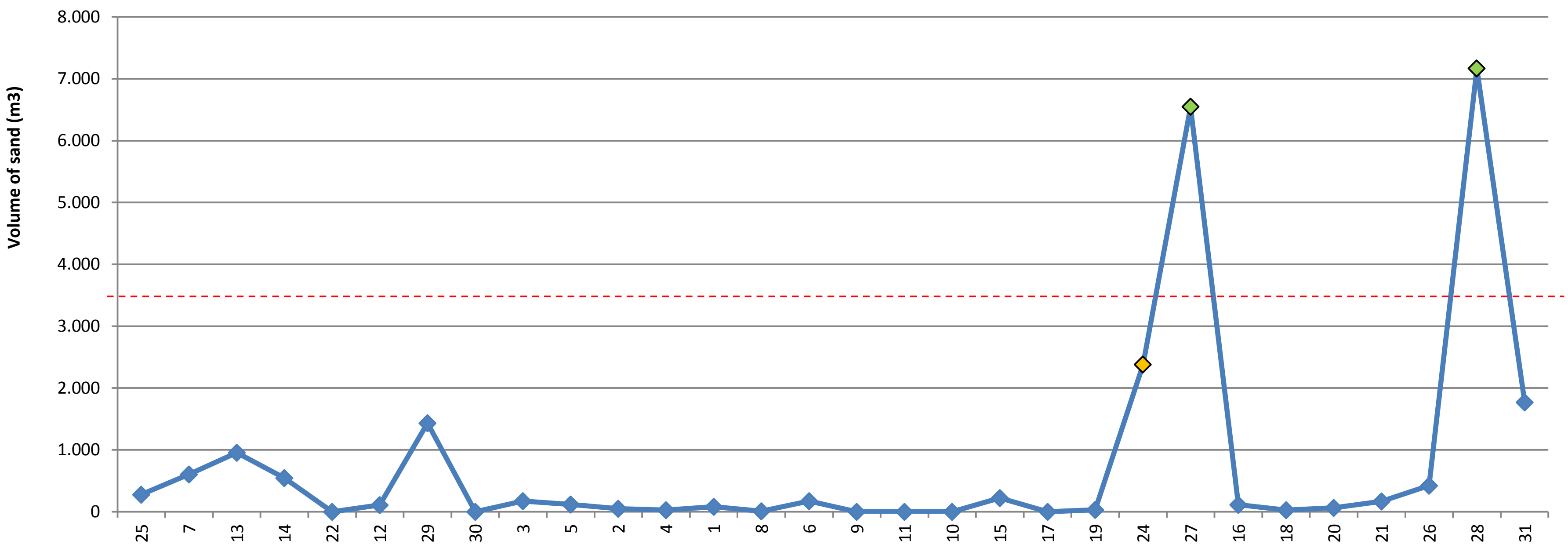
Study Area: Evaluations in 2012 and 2015



De Trincheria, J., Nissen-Petersen, E. (2015). Sand Storage Dams: Performance, cost-efficiency, working principles and constraints. [conference presentation]. International Symposium on rainwater harvesting and resilience (ISRH), Dire Dawa, Ethiopia, 8th-12th June 2015.

2012’s results

Results: Sand storage capacity



- 83% presented volumes of sand <1000 m3
- 2 types of reservoirs: Clogged and graded-bedded

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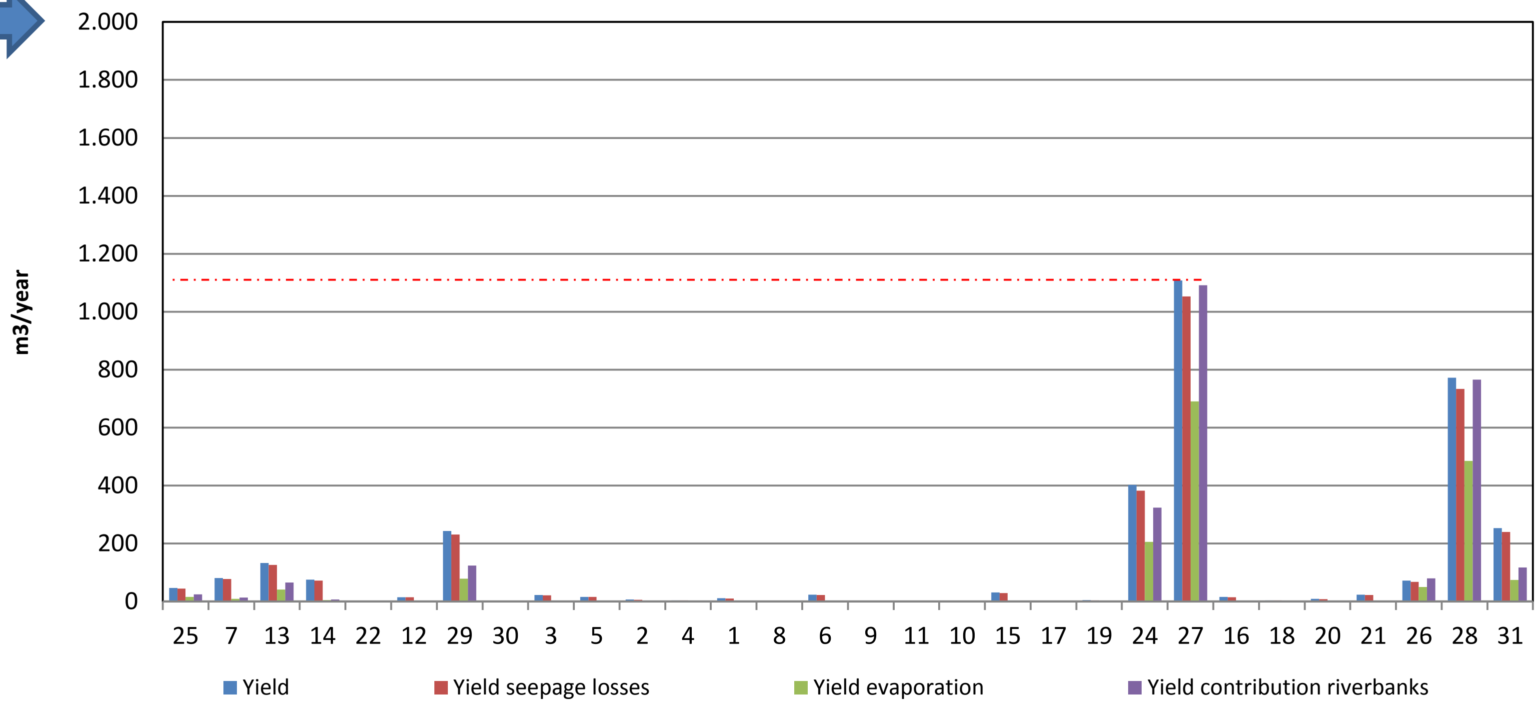
De Trincheria, J., Nissen-Petersen, E., Leal Filho, W., Otterpohl R. (2015). Factors affecting the performance and cost-efficiency of sand storage dams in south-eastern Kenya [conference paper]. E-proceedings of the 36th IAHR World Congress, The Hague, the Netherlands, 28 June – 3 July, 2015.

Yearly water yield of silted-up SDs



- Average specific yield 6.9% → 7 [3,12]% is the specific yield for silty and sandy clay alluvium sediments
- The average yields were 112 m3/year

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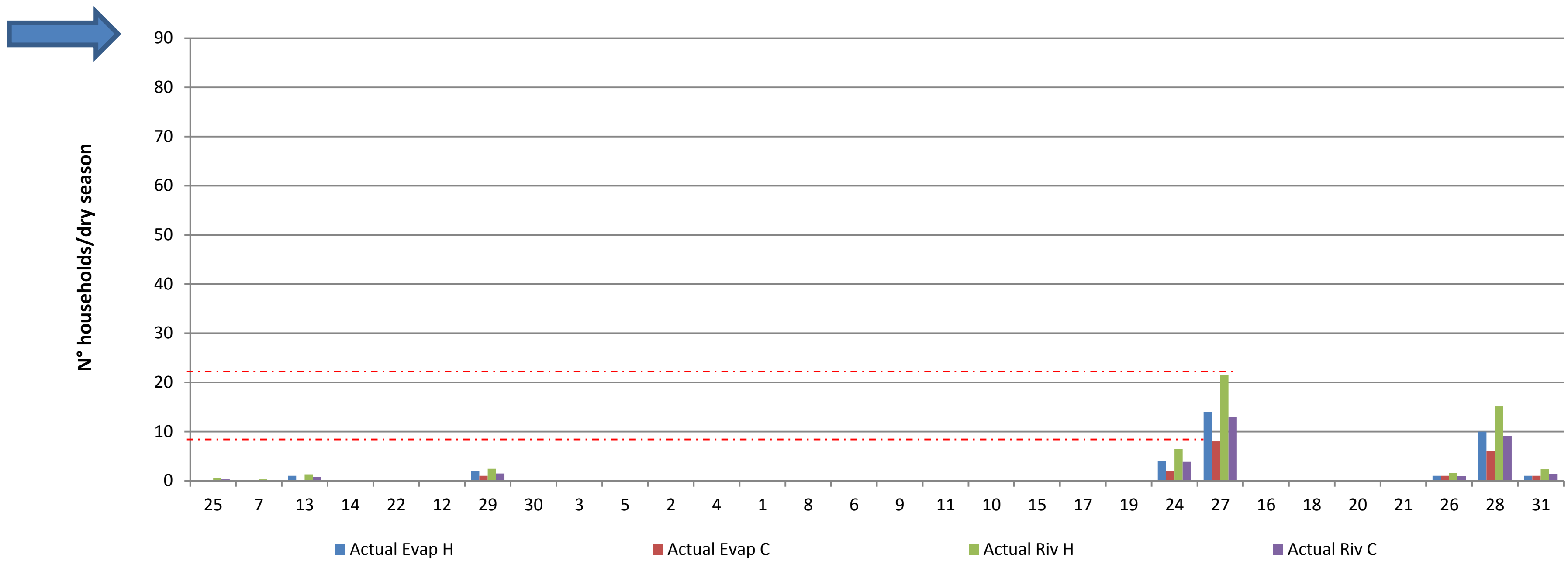
Water supply capacity



- Total aggregated supply capacity for the 30 SDs was 64 and 39 households
- This is equivalent to 320 and 195 individuals
- 17,000 inhabitants in the entire study area
- 660 inhabitants is the typical village size

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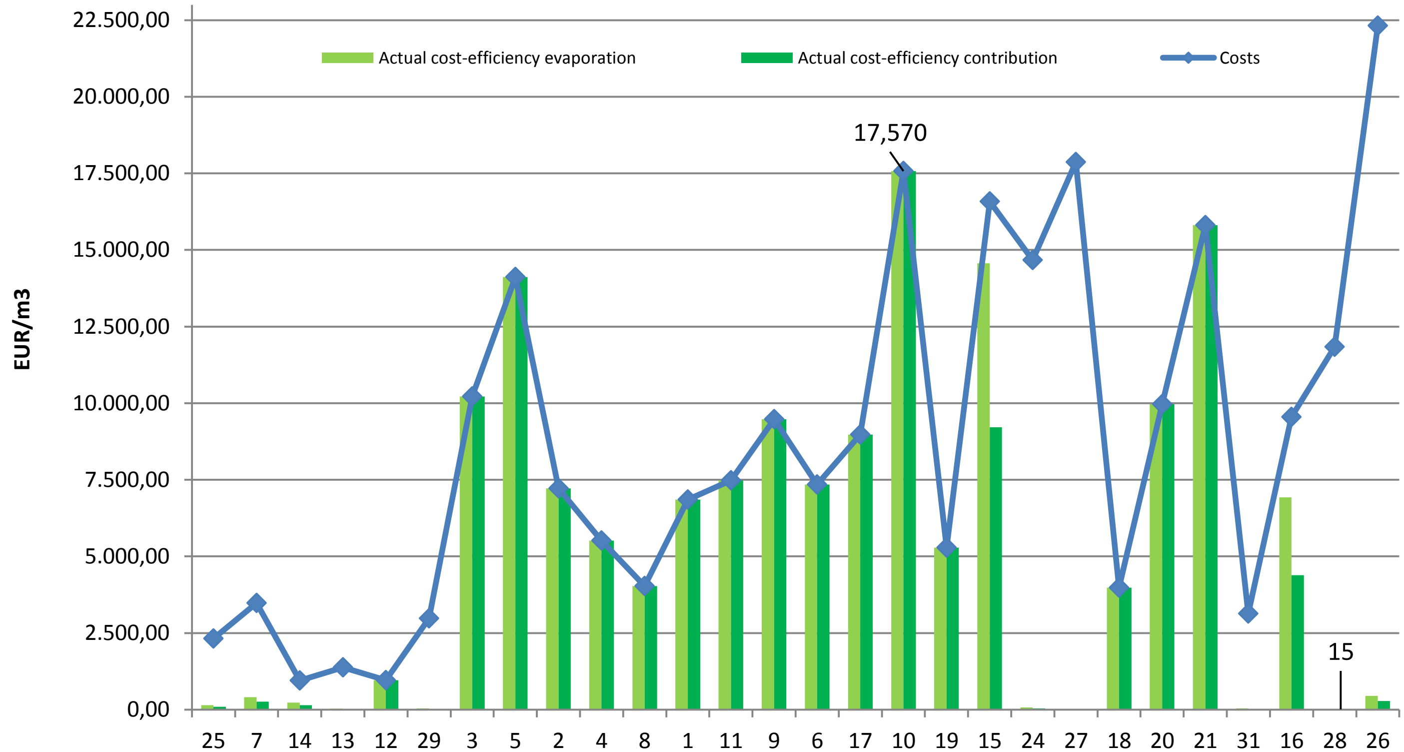
Cost-efficiency

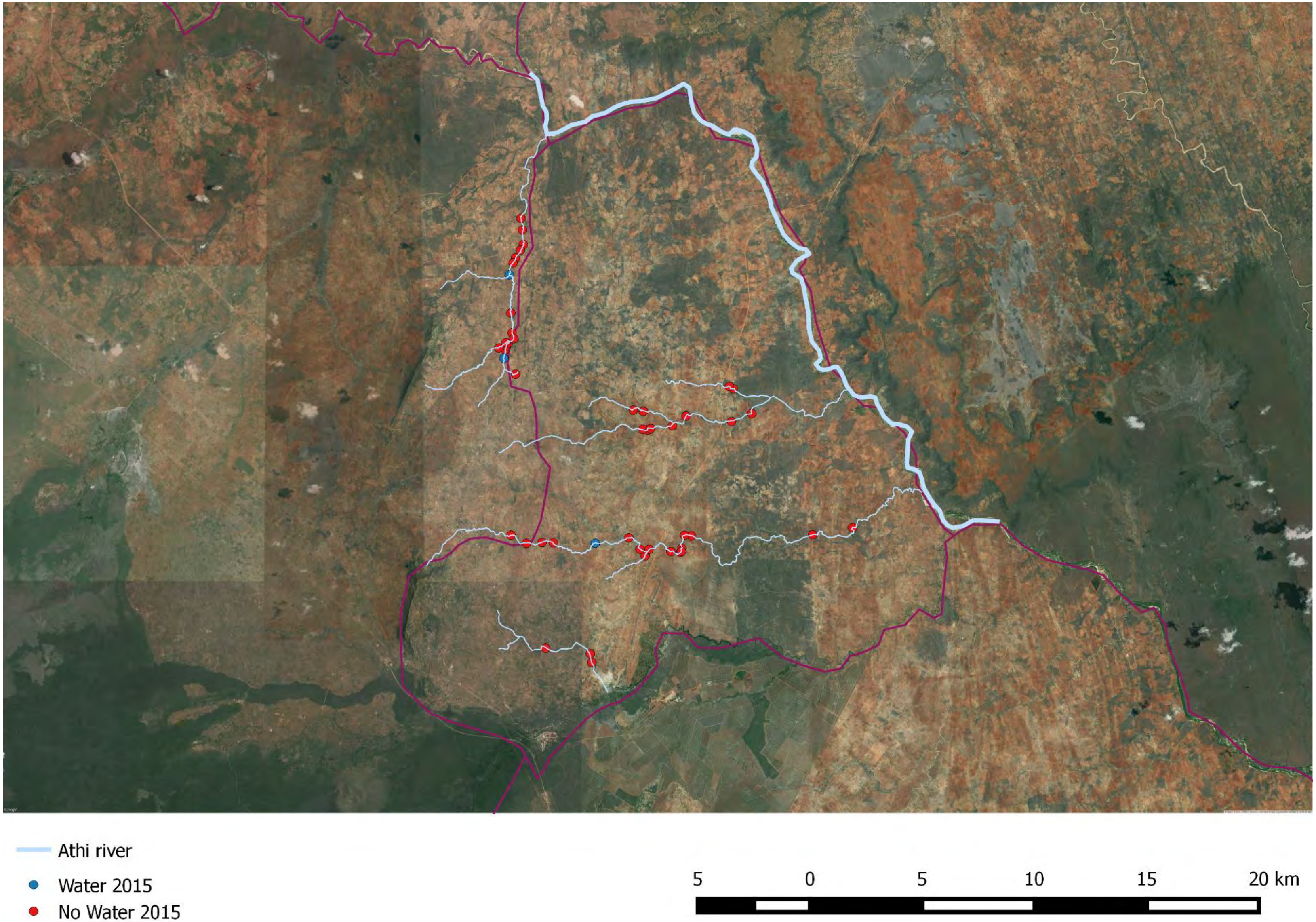


- Total/Average costs →EUR 241,899 à EUR 8,639/SD
- Average yield cost-efficiency: 5,635 EUR/m3
- EUR 134,830 were invested in SDs yielding less than 1 m3/year
- Average supply cost-efficiency: 7,312 EUR/household
- EUR 179,000 invested in SDs that did not supply water to any household

De Trincheria, J., Leal Filho, W., Otterpohl, R. (2017). Towards achieving universal levels of optimal performance by minimising siltation in sand storage dams. Manuscript under review submitted for publication.

2015’s results

2015's Results: water supply during the dry season



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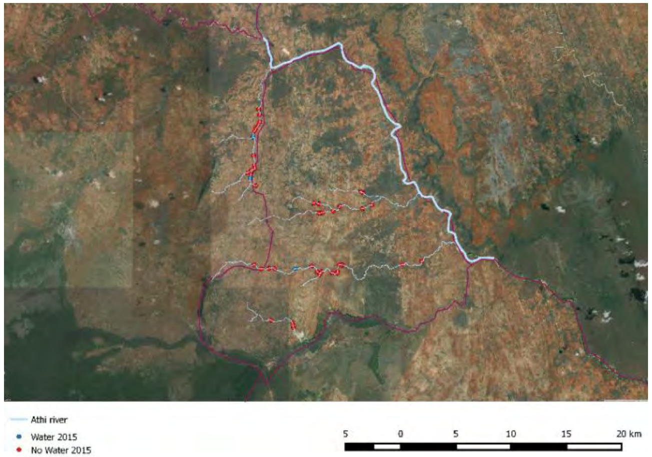
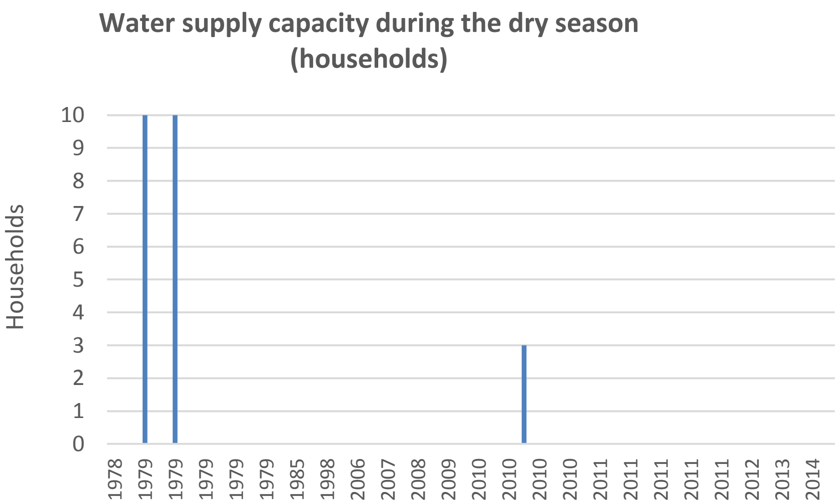
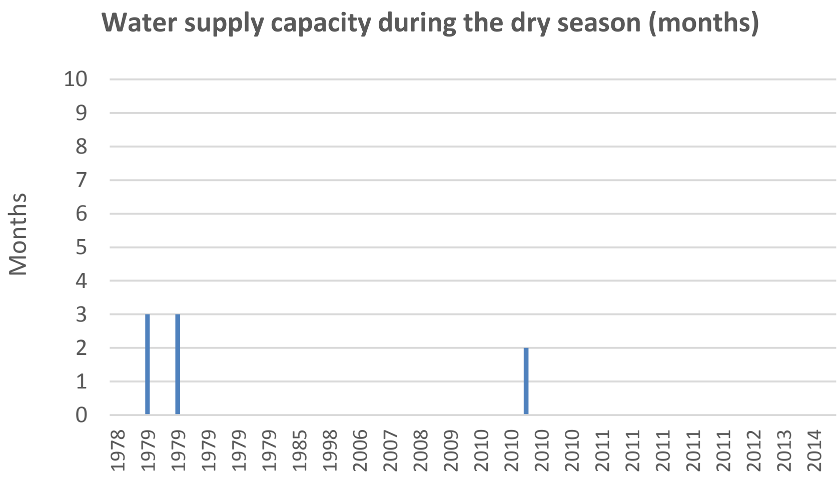
2015's Results: water supply during the dry season







- 6% were supplying water during the dry season

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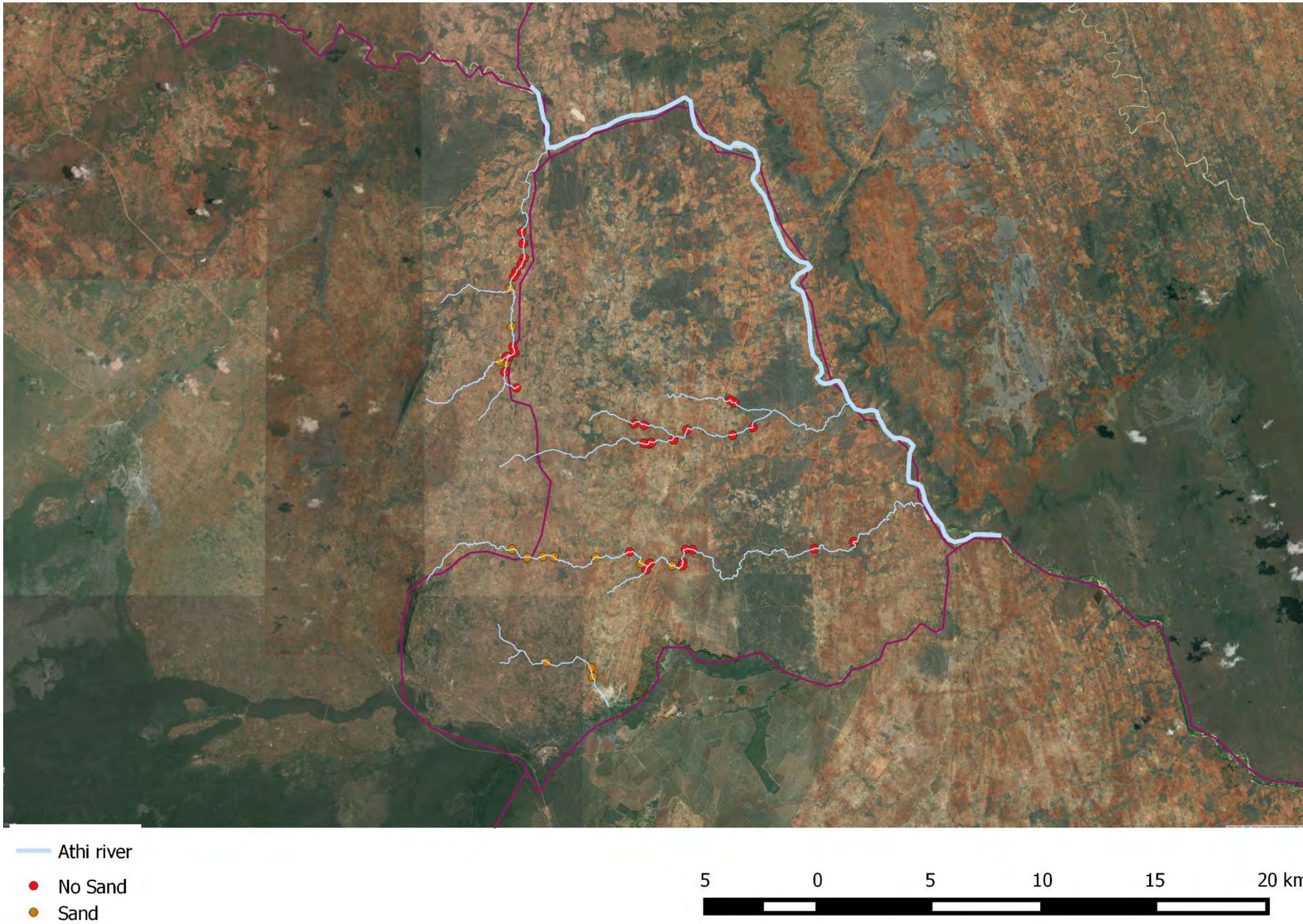
2015's Results: Sand sediments



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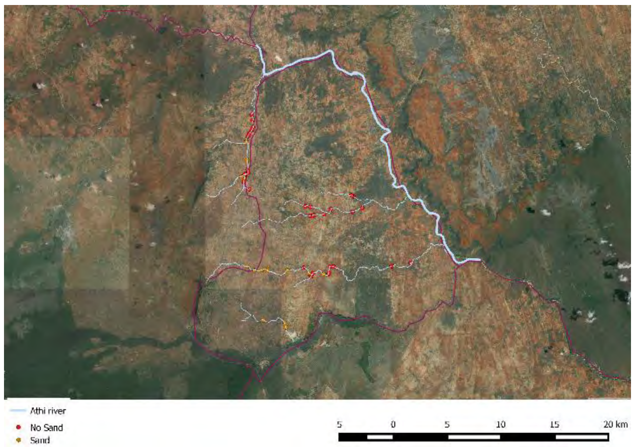
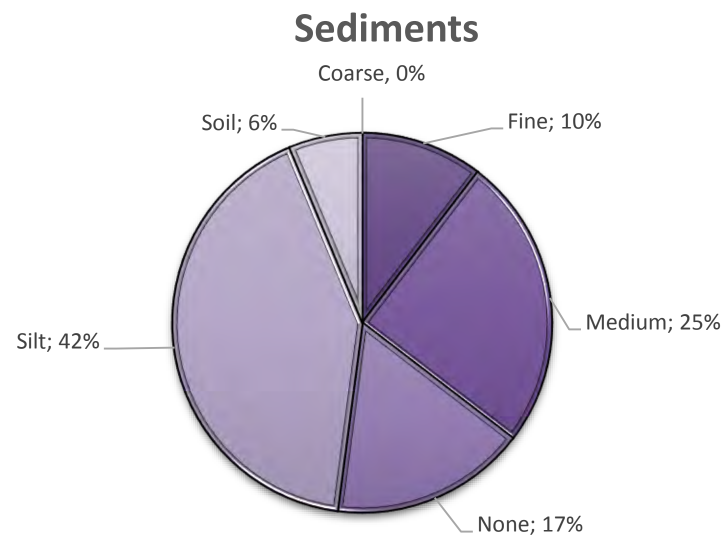
2015’s Results: Sand sediments





- 65% were not effectively accumulating sand sediments
- None were accumulating coarse sand sediments
- Medium and fine sand sediments were present in 35% of the SDs

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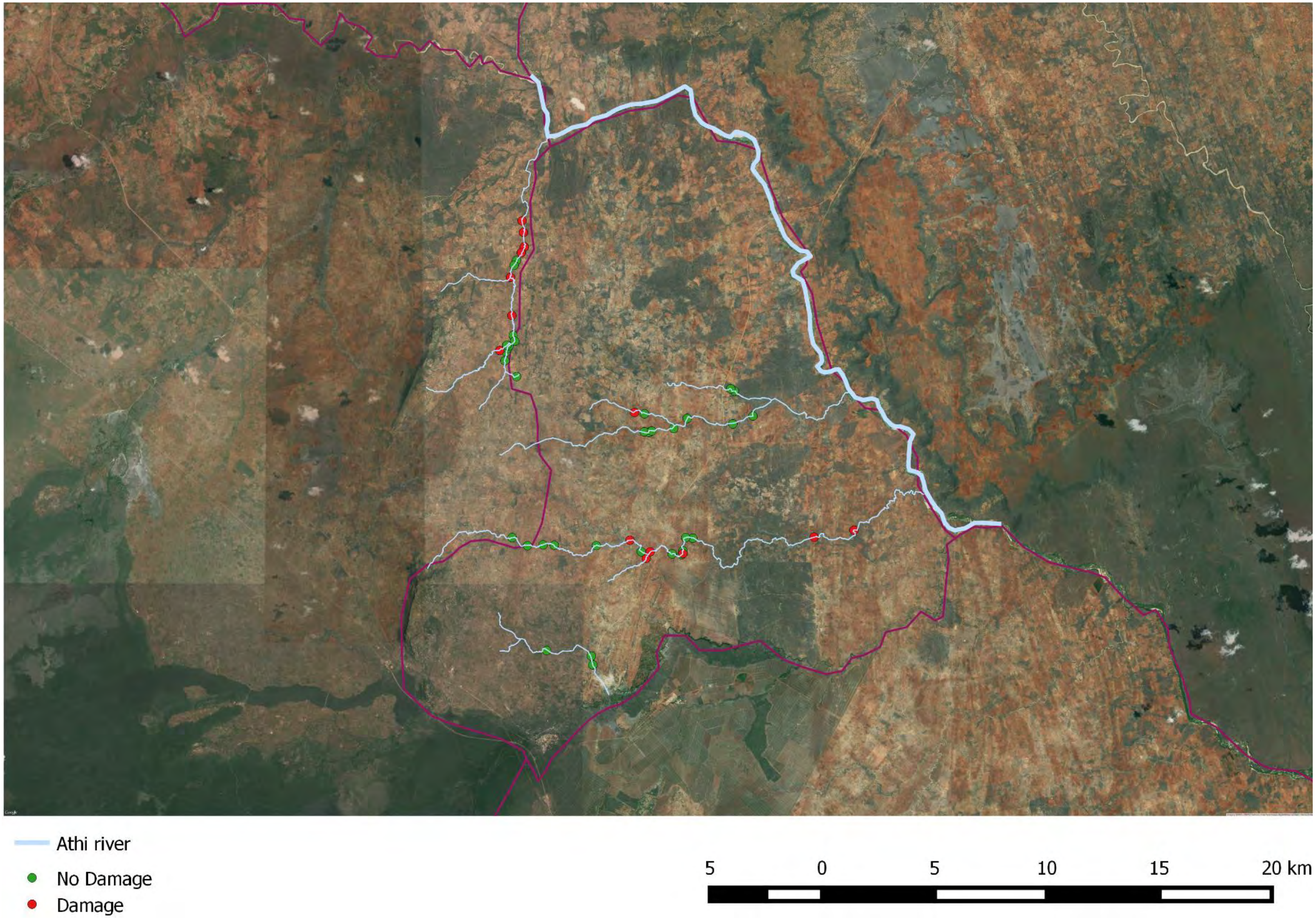
2015's Results: Damaged sand dams



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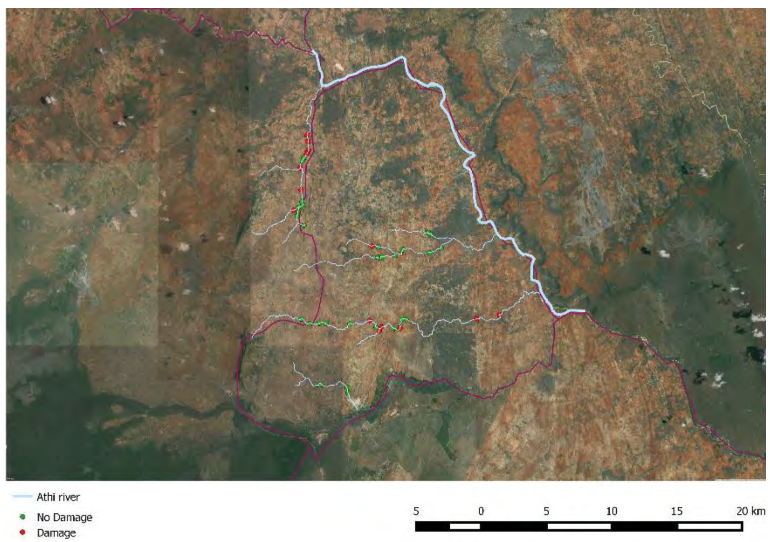
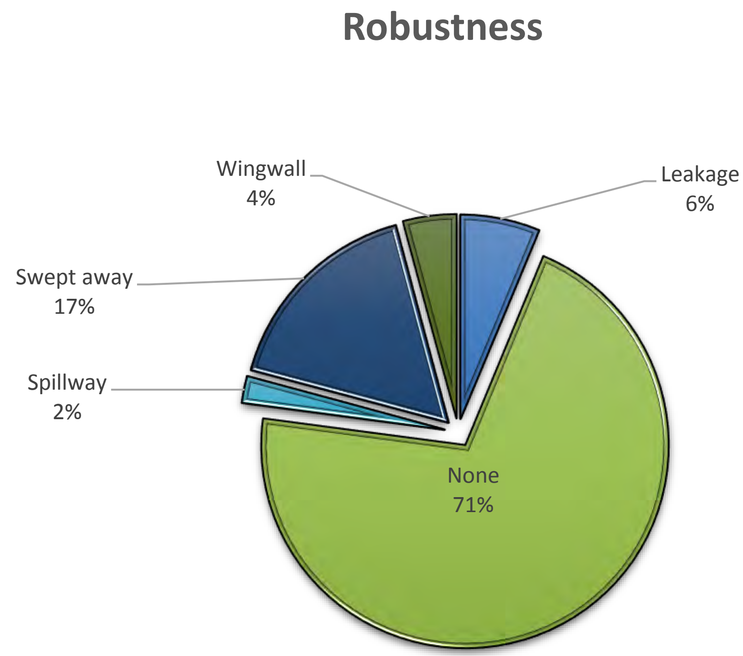
2015's Results: Damaged sand dams





- 29% showed severe structural damages: washed away, leakage, wing walls, spillway

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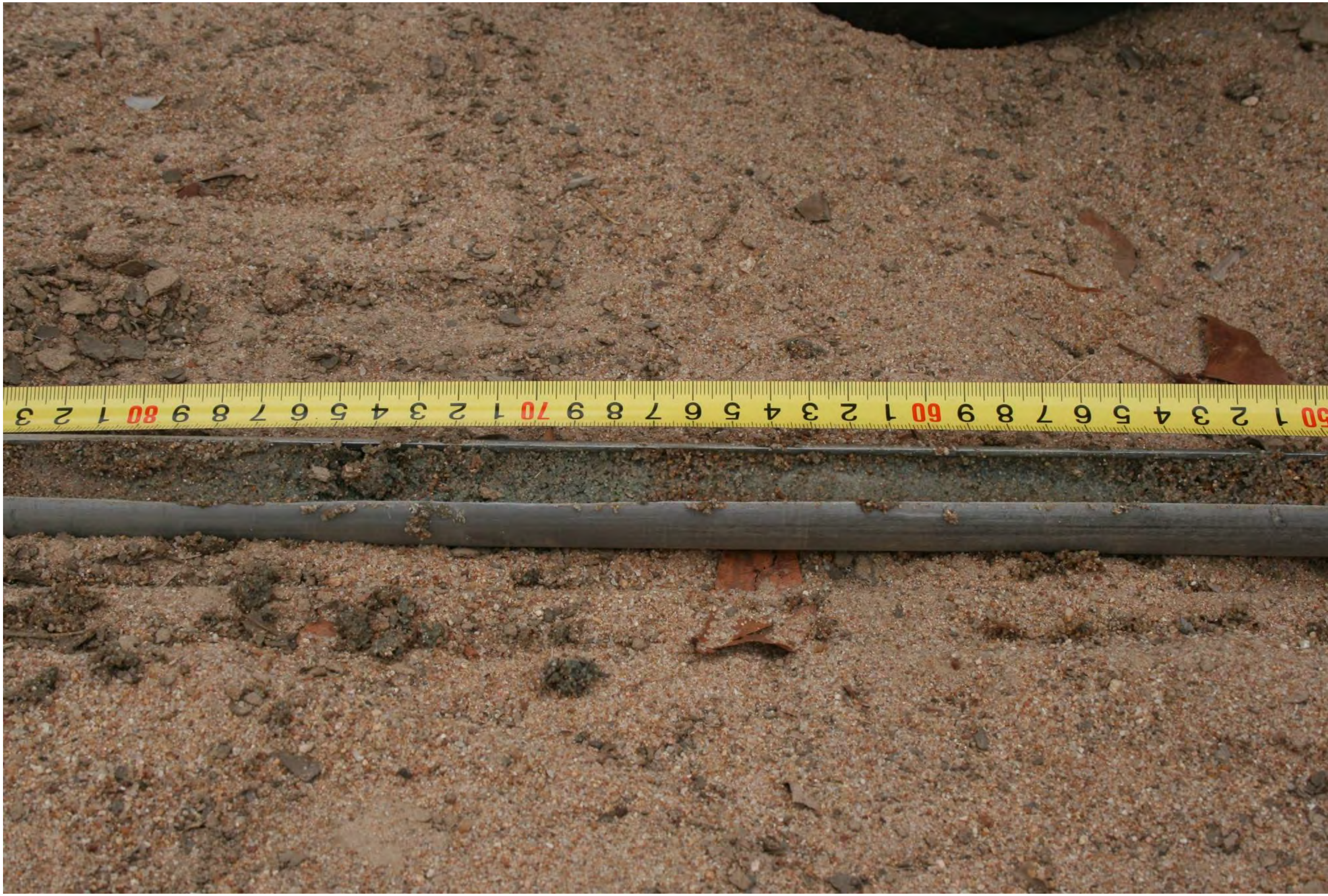
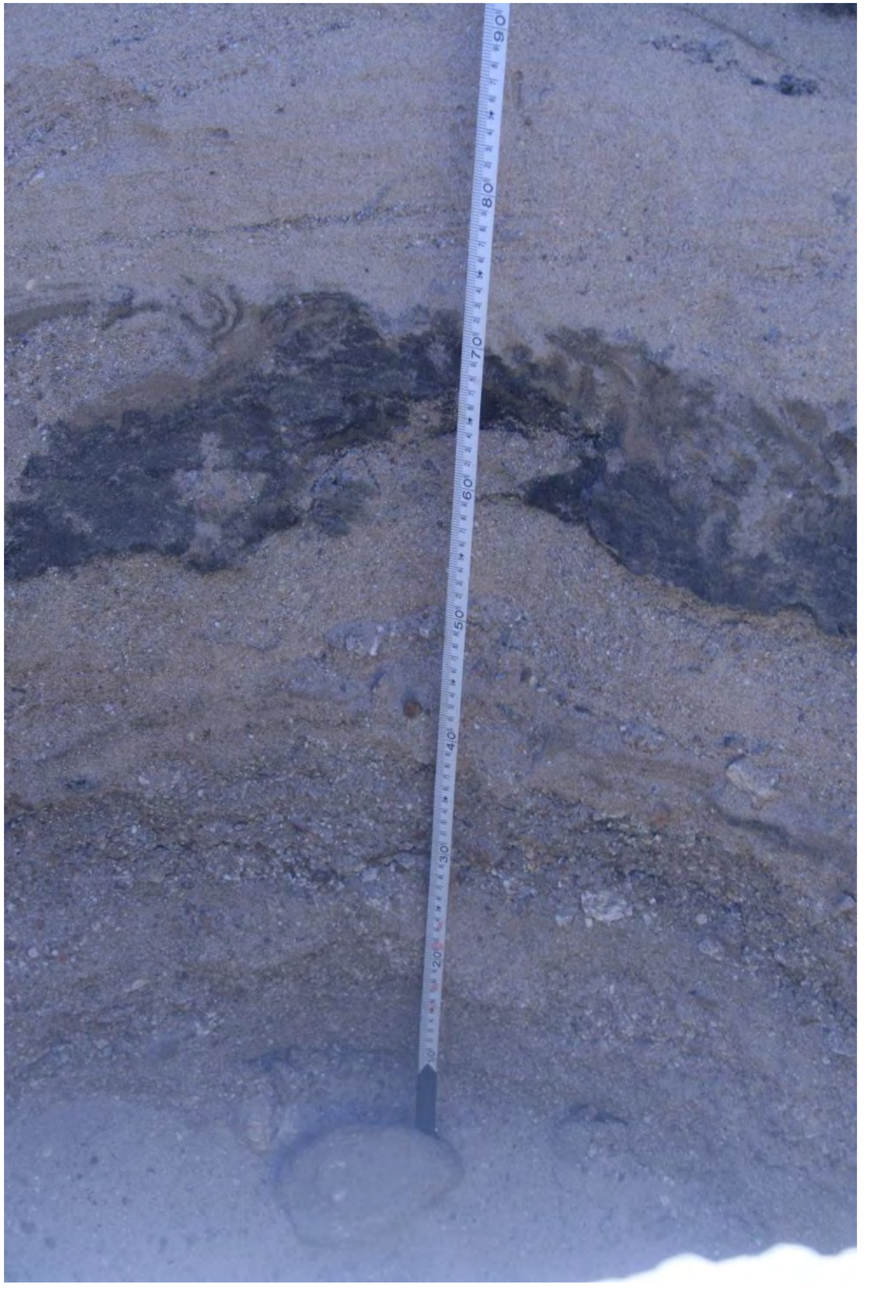
Real-life examples of silted-up SDs

Pictures: Josep de Trincheria




NIKE




90
80
70
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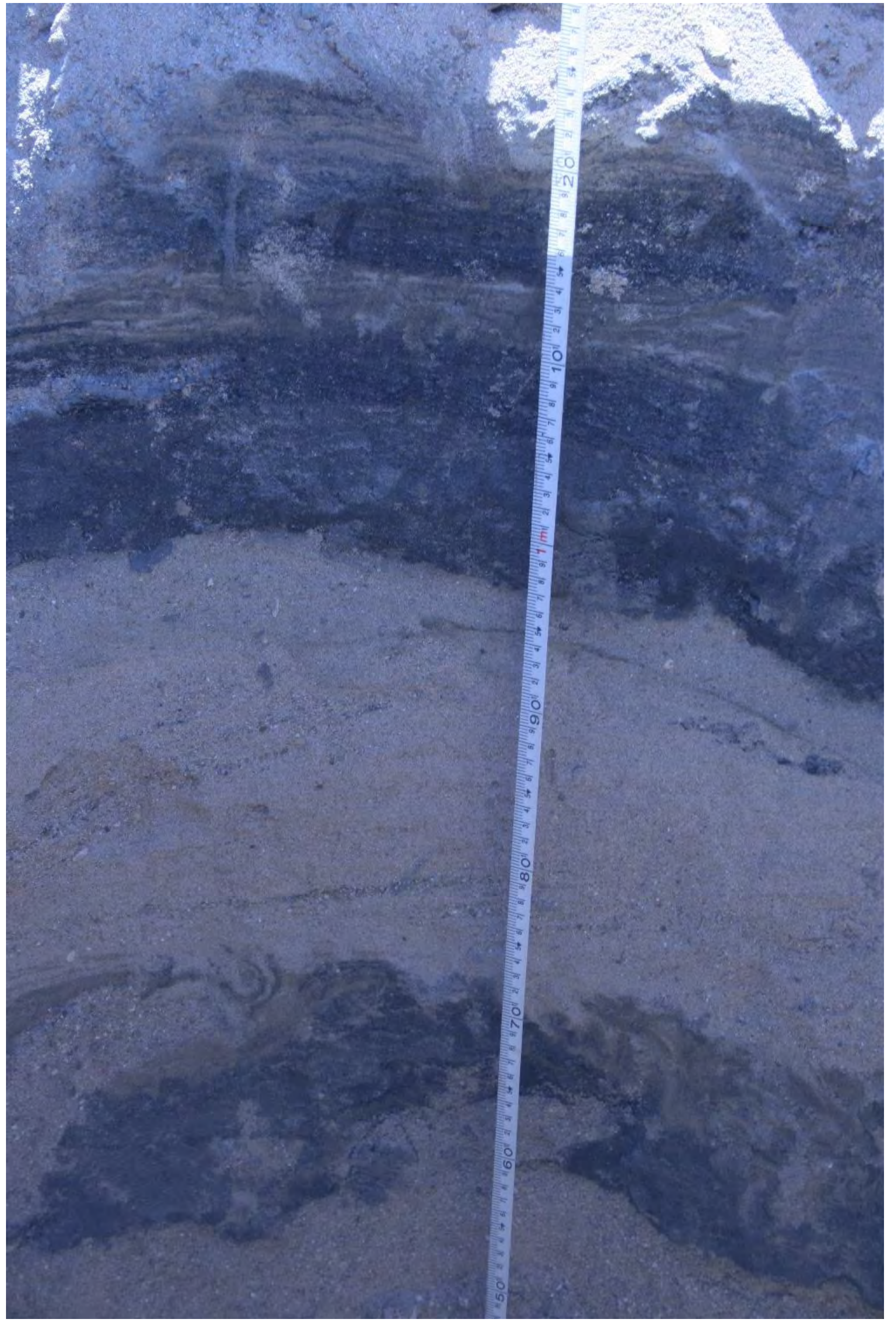

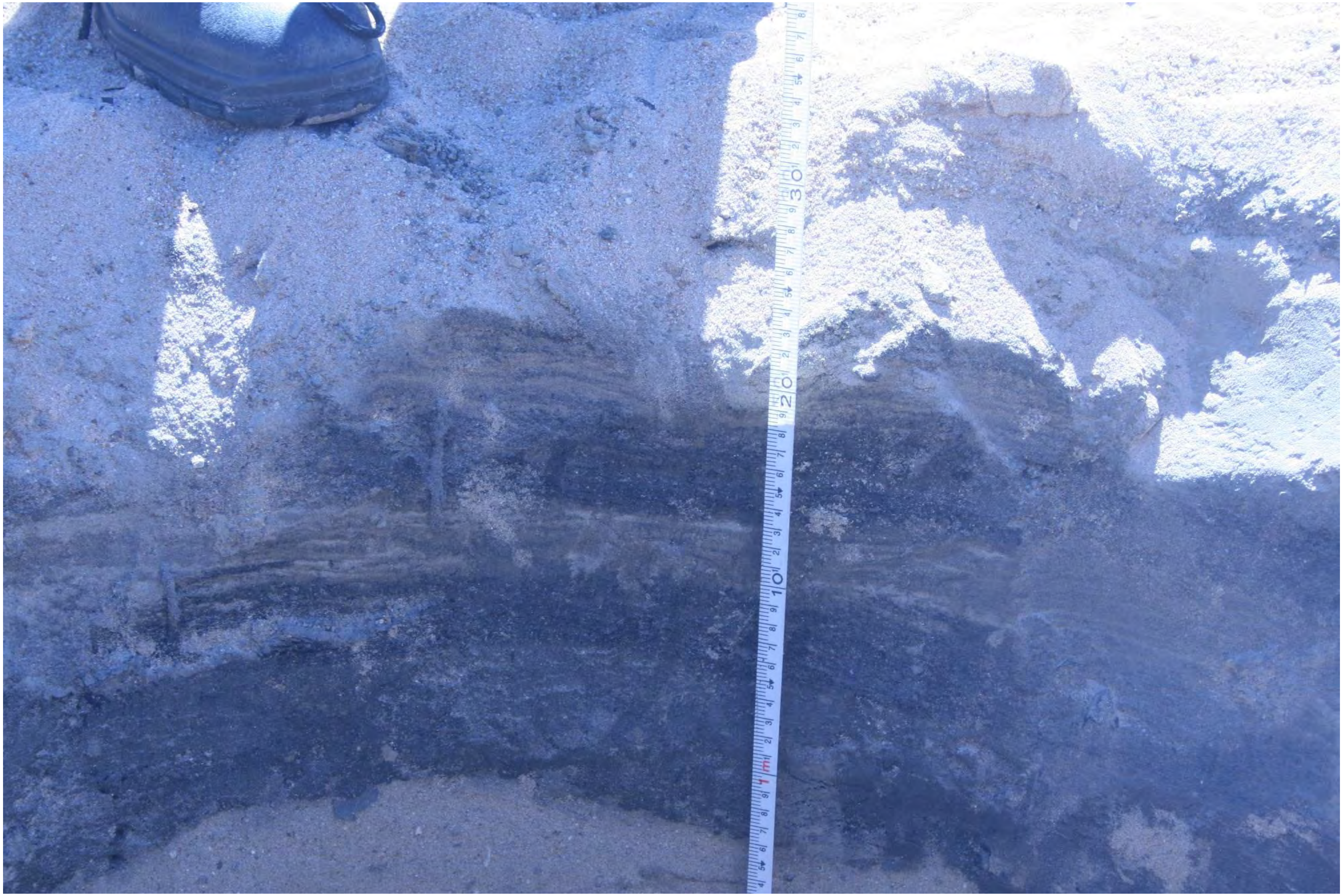

Real-life examples of sand reservoirs

Pictures: Josep de Trincheria


90
80
70
60
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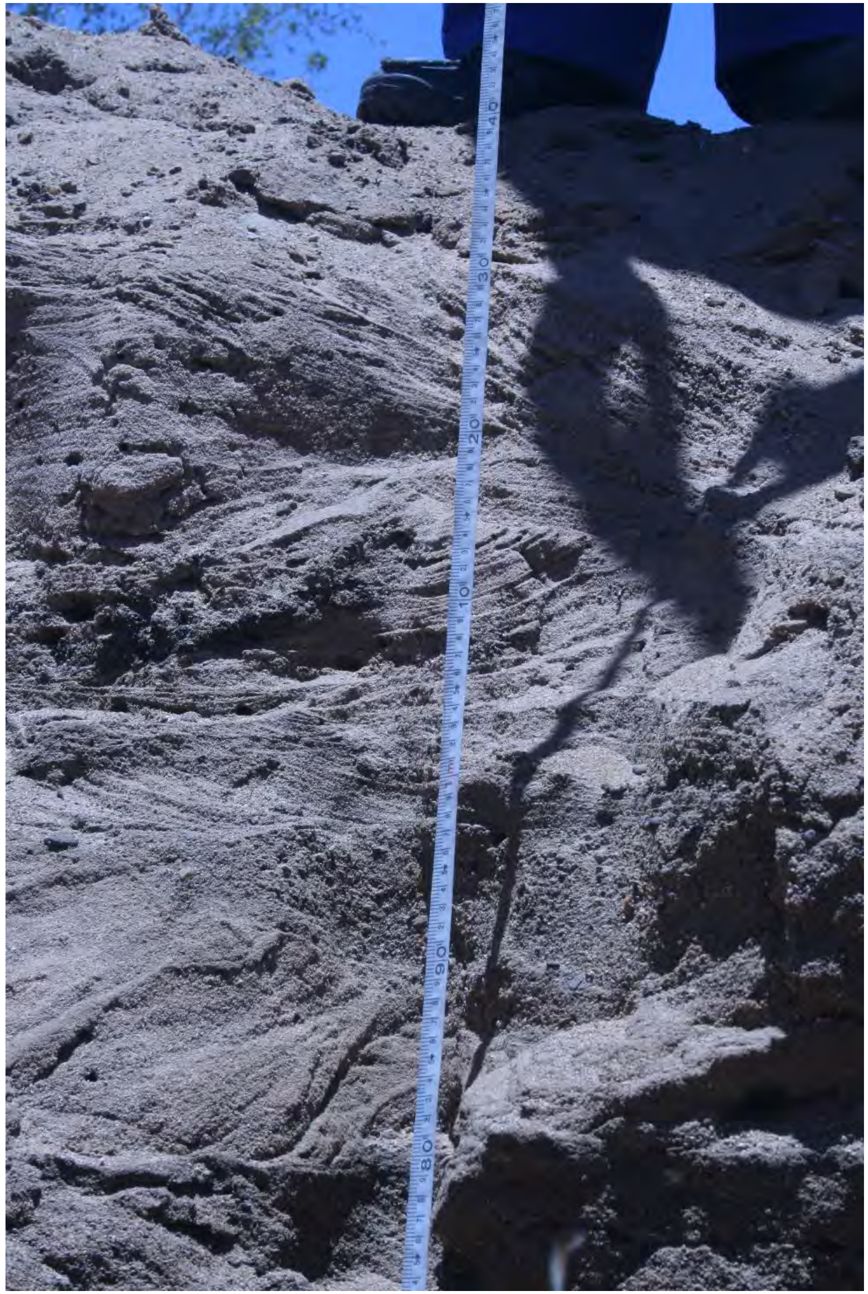

How many silted-up SDs are out there?

- **40%-50% silted-up SDs**

  Viducich, J. (2015). Spillway staging and selective sediment deposition in sand storage dams. MSc Thesis, Oregon State University, Oregon, U.S.

- 4,000 SDs (only in Kenya) → **1,600 silted-up SDs.**

De Trincheria, J., Wibbing, J., Leal Filho, W., Otterpohl, R. (2016). Practical recommendations to prevent, restore and rehabilitate silted-up sand storage dams in arid and semi-arid areas. [conference paper]. 7th RWSN Forum “Water for Everyone” Abidjan, Côte d’Ivoire, 29 Nov - 2 Dec 2016.

Pictures: Josep de Trincheria

Thousands of silted-up SDs

Why this estimation is coherent?

- **50-year literature review on basic principles of rainfall, runoff and sedimentation in drylands**
  - (Powell, 1996; Alexandrov et al., 2003, 2009; Billi, 2011; Reid and Frostick, 2011; Barzilai et al., 2013; Cantalice et al., 2013)
- **Field research about the hydrogeological performance supports this percentage**
  - 60% with 90% in specific areas → (Gijsbertsen and Groen, 2007; Nissen-Petersen, 2011; De Trincheria et al. 2015, 2017, Viducich, 2015)
- **Classical scientific and practical work on technical design of SDs and other hydraulic retention structures**
  - (Wipplinger, 1958; Baurne, 1984; Nilsson, 1988; Nissen-Petersen, 2000, 2006; MWI, 2015)
- **First-hand statement from key implementing agencies working on SDs**
  - Head of a key implementing agency in Kenya stated 40% (Viducich, 2015)
  - Erik Nissen-Petersen with more 40 years of practical experience all over sub-Saharan Africa
  - Key implementing agencies and practitioners in Kenya, Zimbabwe, Ethiopia and Eritrea
- **Universality of the one-stage spillway construction process**

De Trincheria, J., Wibbing, J., Leal Filho, W., Otterpohl, R. (2016). Practical recommendations to prevent, restore and rehabilitate silted-up sand storage dams in arid and semi-arid areas. [conference paper]. 7th RWSN Forum “Water for Everyone” Abidjan, Côte d’Ivoire, 29 Nov - 2 Dec 2016.

Investment on silted-up SDs

- If construction costs per SD are 8,000 EUR AND there are 1,600 are silted-up SDs.

→ 12.8 Million EUR in silted-up SDs that:

- Do not yield or supply of water
- Exhibit poor performances, low cost-efficiencies and insufficient positive impacts to local communities

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How to minimise siltation?

Build the spillway by stages of reduced height in order to maximise the probability to block the bedload in as many different conditions as possible.

Stage 1. Spillway is 50 cm above the sand level.

Stage 2. Flood has brought sand to the level of the spillway.

Stage 3. Spillway is raised to 50 cm above new sand level.

Stage 4. Flood has deposited sand to the new level of the spillway.

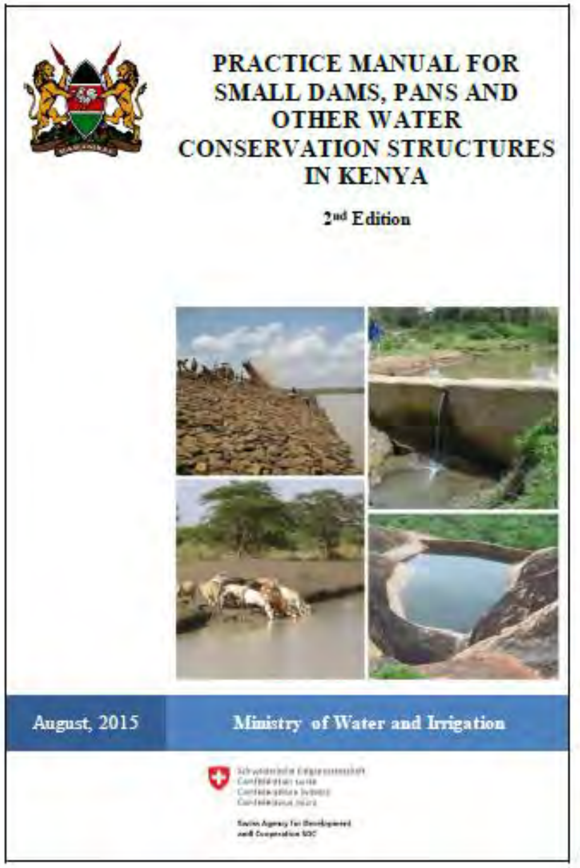
Stage 5. Spillway is raised to 50 cm above new sand level.

Stage 6. This procedure is repeated until the spillway is fully closed.

Nissen-Petersen, E. (2006). Water from Dry Riverbeds. How dry and sandy riverbeds can be turned into water sources by hand-dug wells, subsurface dams, weirs and sand dams. ASAL Consultants Limited for the Danish International Development Assistance.

To build by stages of reduced height is the recommended method in the 2015‘s Kenyan Ministry of Water and Irrigation „PRACTICE MANUAL FOR SMALL DAMS, PANS AND OTHER WATER CONSERVATION STRUCTURES IN KENYA“.

Available at:
http://smalldamsguidelines.water.go.ke/useful_downloads/pdf/PRACTICE_MANUAL_FOR_SMALL_DAMS_PANS_AND_OTHER_WATER_CONSERVATION_STRUCTURES_IN_KENYA.pdf



Methodology to build by stages of reduced height

Using a fixed stage height from 20 cm to 60 cm at a case-by-case basis

Case-by-case variables

1. Final spillway height required to meet local communities needs.
2. Type of stream: ephemeral or intermittent.
3. Number of rainfall events during the wet season
4. Original and target grain-size particle of the reservoir.
5. Assumed historical magnitude of bedload transport.
6. Total construction period time feasible

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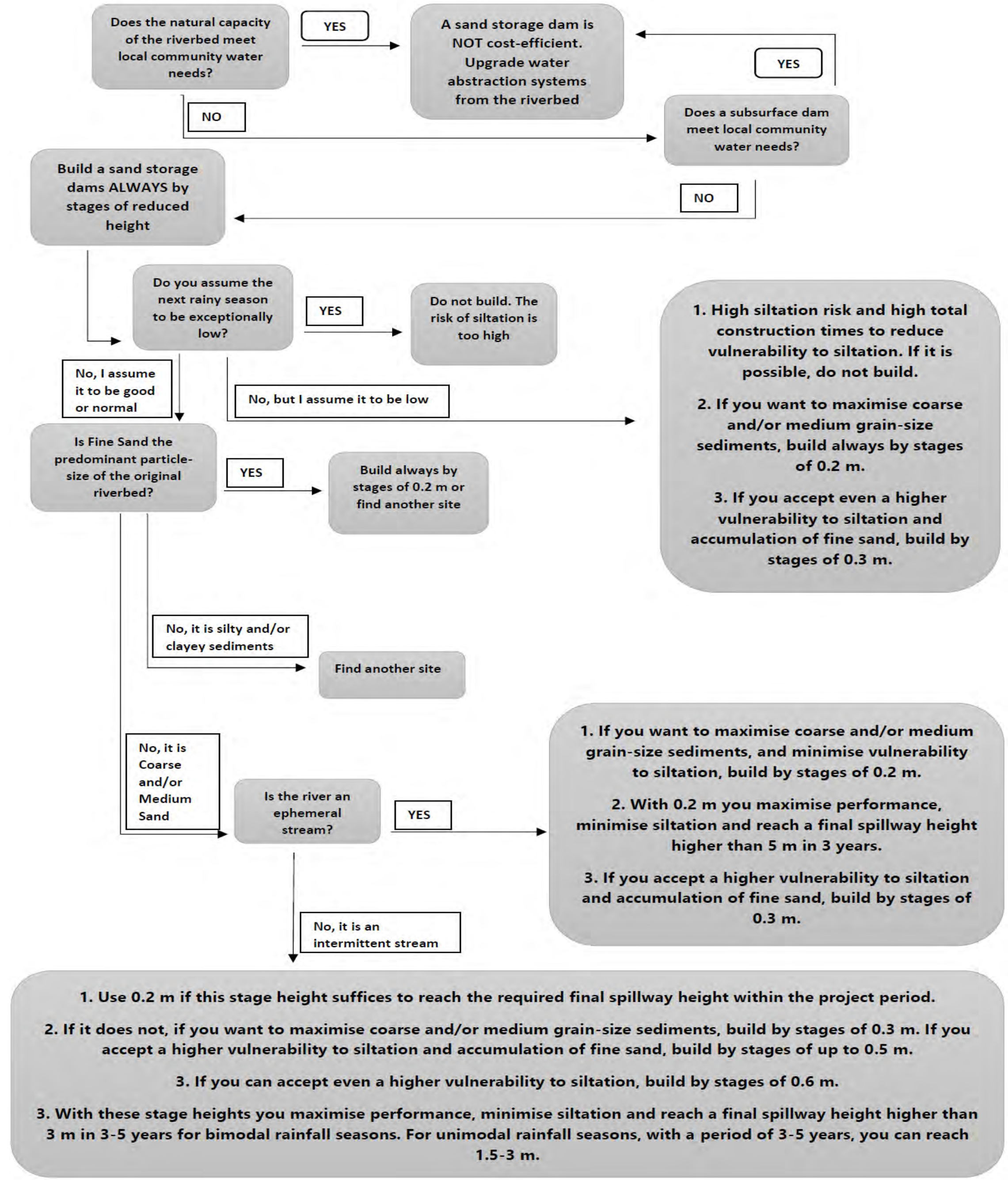
Recommended stage heights to be used on a case-by-case basis:
CA= Predominant particle grain-size of the original riverbed (C=Coarse, M=Medium, F= Fine); R= Type of seasonal river (I=Intermittent, i.e. continuous flow of water during wet periods; E=Ephemeral, i.e. flow of water only after a rainfall event); S= Number of rainy seasons/year; GR= Predominant particle grain-size of the reservoir created by the sand storage dam; H= Height of stage height in exceptionally good, good and normal rainfall years (m); H(P)= H during poor rainfall years (m).

#	CA	R	S	GR	H	H(P)
1	C	I	1	C,M	0.3-0.5	0.2
2	C	I	1	F	0.6	0.3
3	M	I	1	M	0.3	0.2
4	M	I	1	F	0.6	0.3
5	F	I	1	F	0.2	0.2
6	C	I	2	C, M	0.3-0.5	0.2
7	C	I	2	F	0.6	0.3
8	M	I	2	M	0.3	0.2
9	M	I	2	F	0.6	0.3
10	F	I	2	F	0.2	0.2
11	C	E	1	C	0.2-0.3	0.2
12	C	E	1	F,M	0.3	0.3
13	M	E	1	M	0.2	0.2
14	M	E	1	F	0.3	0.3
15	F	E	1	F	0.2	0.2
16	C	E	2	C	0.2-0.3	0.2
17	C	E	2	F,M	0.3	0.3
18	M	E	2	M	0.2	0.2
19	M	E	2	F	0.3	0.3
20	F	E	2	F	0.2	0.2

De Trincheria, J., Wibbing, J., Leal Filho, W., Otterpohl, R. (2016). Practical recommendations to prevent, restore and rehabilitate silted-up sand storage dams in arid and semi-arid areas. [conference paper]. 7th RWSN Forum "Water for Everyone" Abidjan, Côte d'Ivoire, 29 Nov - 2 Dec 2016.

Building by stages of reduced height



De Trincheria, J., Wibbing, J., Leal Filho, W., Otterpohl, R. (2016). Practical recommendations to prevent, restore and rehabilitate silted-up sand storage dams in arid and semi-arid areas. [conference paper]. 7th RWSN Forum “Water for Everyone” Abidjan, Côte d’Ivoire, 29 Nov - 2 Dec 2016.

Total construction time

Using a fixed stage height at a case-by-case basis

- **In ephemeral, with stage heights from 20 cm to 30 cm in normal rainfall years under unimodal rainfall season (8 shower events).**

→ Spillway heights in 1 year: 1.6 m to 2.4 m.

→ Spillway heights in 3 years 4.8 m, 7.2 m.

→ Spillway heights in 5 years 8 m, 12 m.

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Using a fixed stage height at a case-by-case basis

- **In intermittent streams, with stage heights from 20 cm to 60 cm under in normal rainfall years under unimodal rainfall season (1 shower event!)**

→ For bimodal rainfall seasons get multiplied by 2!

→ Spillway heights in 1 year 0.2 m to 0.6 m.

→ Spillway heights in 3 years 0.6 to 1.8 m.

→ Spillway heights in 5 years 1 to 3 m.

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Construction costs

- Building by stages is NOT more expensive than building in one-stage → Most of construction process is in one go.
  - In Zimbabwe, average multi-stage spillway construction ca. USD 4,000
- A multi-stage spillway construction process can be significantly less expensive than building in one stage using current construction procedures.

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De Trincheria, J., Wibbing, J., Leal Filho, W., Otterpohl, R. (2016). Practical recommendations to prevent, restore and rehabilitate silted-up sand storage dams in arid and semi-arid areas. [conference paper]. 7th RWSN Forum "Water for Everyone" Abidjan, Côte d'Ivoire, 29 Nov - 2 Dec 2016.

Community mobilisation

- Few examples in Kenya but many in Zimbabwe illustrate that successfully involving local communities during the rainy season in a multi-stage sand storage dam is possible.

- Consider involving 2 paid local artisans to raise each stage after a runoff event.

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Multi-stage spillway SDs

Pictures: Josep de Trincheria

Minimising seepage

Causes leading to seepage losses

1. Building the wall on boulders → More on construction part
2. Permeable bedrocks
3. Predominance of boulders on the riverbed
4. Fractured sedimentary rocks on the riverbed
5. Seepage can be beneficial for boreholes/deep hand-dug wells on the riverbanks but subsurface dams may show inherent advantages

Nissen-Petersen, E. (2006). Water from Dry Riverbeds. How dry and sandy riverbeds can be turned into water sources by hand-dug wells, subsurface dams, weirs and sand dams. ASAL Consultants Limited for the Danish International Development Assistance.

Seepage losses

Pictures: Josep de Trincheria

Seepage losses

Pictures: Josep de Trincheria

Seepage losses

Pictures: Josep de Trincheria

Seepage losses

Pictures: Josep de Trincheria

Unsuitable sections due to seepage

Systematically to avoid sites with **predominant presence of large boulders, sedimentary rocks standing vertically in the riverbed, fractured granite or gneiss rocks**

Pictures: E. Nissen-Petersen

Careful with seepage!

Pictures: Kitui County, 2017

Minimise seepage by building on clay or murram

The ALDEV foundation has a 0.2 m deep base with a 1.0 m deep trench excavated into an underground dyke of soil.

The NGO foundation is built onto boulders and fractured rocks that often drain water out of the dam reservoir.

Nissen-Petersen, E., De Trincheria, J. (2015) [conference presentation]. How to get more water from sand dams –For half the cost. International Rainwater Harvesting and Resilience Symposium, Addis Ababa, Ethiopia, 1st-12th June 2015.

Minimising evaporation

Evaporation losses

- 10% at 60 cm, 0% at 0,9-1,0 m, but for coarse sand sediments→ Higher depths with fine sand, and silty and clayey sediments similar rates than surface water!

- Reservoirs with shallow sand depths are vulnerable → evaporation up to 0,6 m -1.0 m along all the surface!

- Evaporation is undervalued and should always be considered in the calculation of the yield
  → Subtract the corresponding sand storage capacity for the 1 m of sand at the surface

De Trincheria, J., Nissen-Petersen, E., Leal Filho, W., Otterpohl R. (2015). Factors affecting the performance and cost-efficiency of sand storage dams in south-eastern Kenya [conference paper]. E-proceedings of the 36th IAHR World Congress, The Hague, the Netherlands, 28 June – 3 July, 2015.

Minimising evaporation

1. Evaporation is undervalued and should always be considered in the calculation of the yield.
   → Subtract the corresponding sand storage capacity for the 1 m of sand at the surface.

2. Sand reservoir always benefiting from the deepest sections of the riverbed section, so as to compensate free storage capacity with evaporation losses.

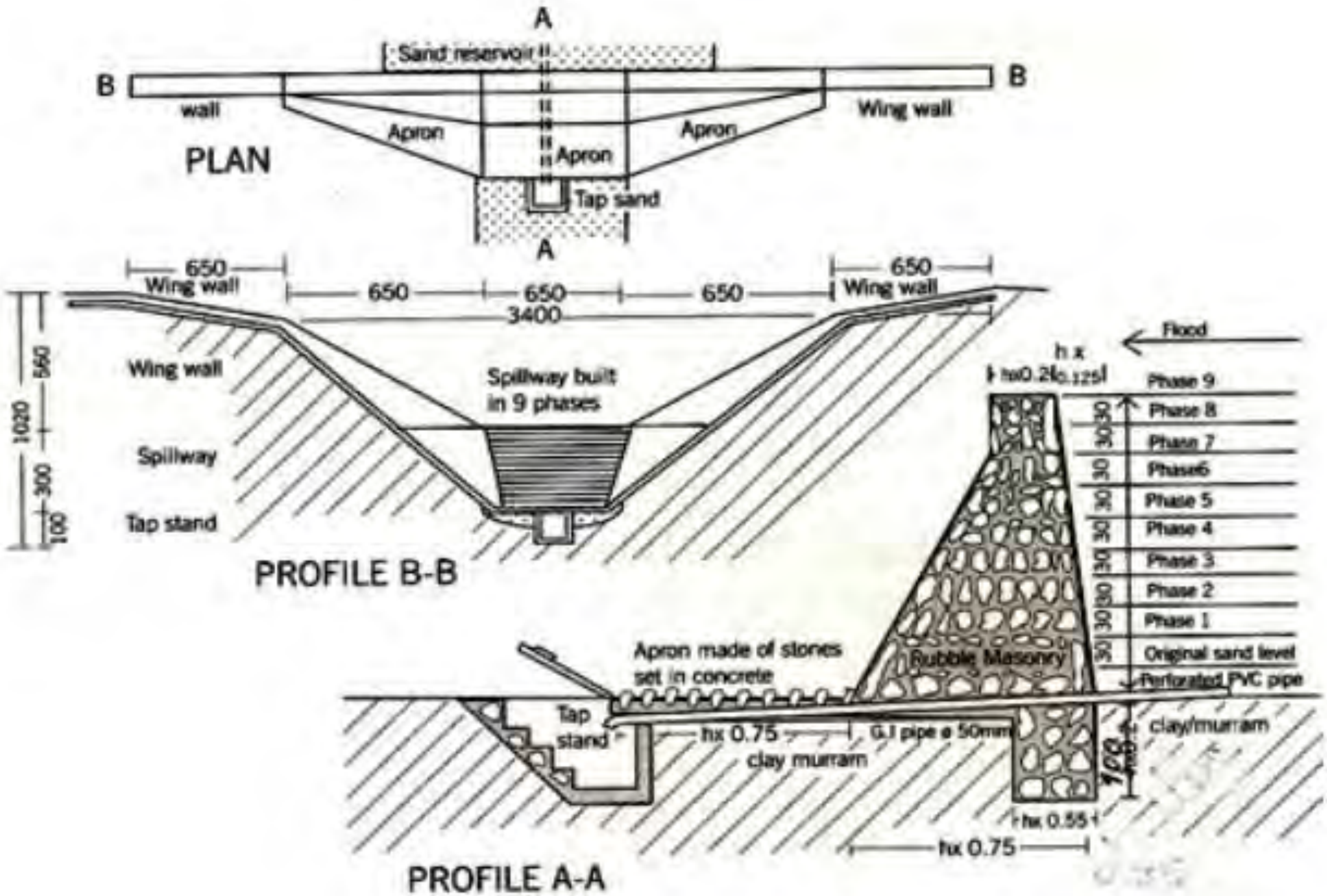
3. Avoid reservoirs with predominant capacity of fine sand because evaporation depth is higher than 1m.

4. Avoid siltation at any extent so as to reduce vulnerability to evaporation.

De Trincheria, J., Nissen-Petersen, E., Leal Filho, W., Otterpohl R. (2015). Factors affecting the performance and cost-efficiency of sand storage dams in south-eastern Kenya [conference paper]. E-proceedings of the 36th IAHR World Congress, The Hague, the Netherlands, 28 June – 3 July, 2015.

Construction costs

Use the ALDEV Design



Nissen-Petersen, E., De Trincheria, J. (2015) [conference presentation]. How to get more water from sand dams –For half the cost. International Rainwater Harvesting and Resilience Symposium, Addis Ababa, Ethiopia, 1st-12th June 2015.

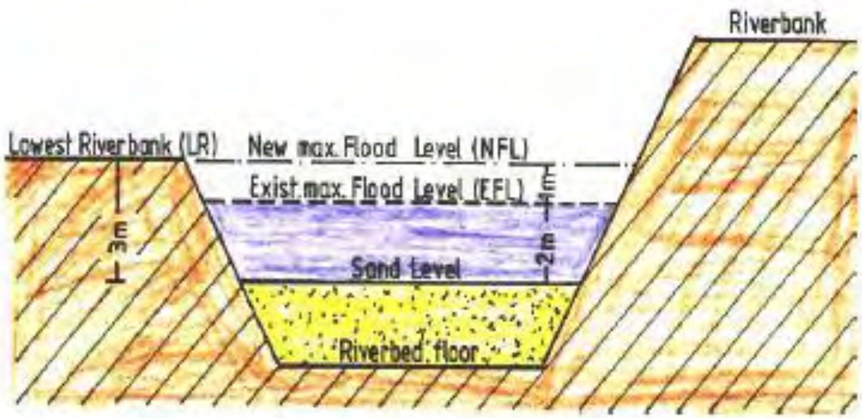
Vulnerability to erosion!

SDs are vulnerable to be washed away by the erosive action of runoff floods after a few rainy seasons due to inadequate or missing spill-over aprons and/or wing walls, and excessive height of the spillway, or simply above than average rainfalls

Nissen-Petersen, E. (2006). Water from Dry Riverbeds. How dry and sandy riverbeds can be turned into water sources by hand-dug wells, subsurface dams, weirs and sand dams. ASAL Consultants Limited for the Danish International Development Assistance.

Determine maximum final spillway height

Use maximum flood design



The maximum height of a spillway is found by deducting the maximum flood level (MFL) from the height of lowest riverbank (LR).

Avoid trial and Error design

The spillway of this sand dam was too high and the wing walls were too low thereby allowing the floodwater to remove the riverbank and make a new riverbed outside the sand dam.

Nissen-Petersen, E., De Trincheria, J. (2015) [conference presentation]. How to get more water from sand dams –For half the cost. International Rainwater Harvesting and Resilience Symposium, Addis Ababa, Ethiopia, 1st-12th June 2015.

Minimise construction costs

1. Build on underground dykes to reduce costs and gain free storage capacity.

2. Use rubble stone masonry with costs ca. 30% lower than concrete with timber shuttering.

Nissen-Petersen, E., De Trincheria, J. (2015) [conference presentation]. How to get more water from sand dams –For half the cost. International Rainwater Harvesting and Resilience Symposium, Addis Ababa, Ethiopia, 1st-12th June 2015.

3. Remove excessive concrete

Remove the steps and built the wing walls as in the photo below.

Make the crest straight and only 0.3 m wide as in the photo below.

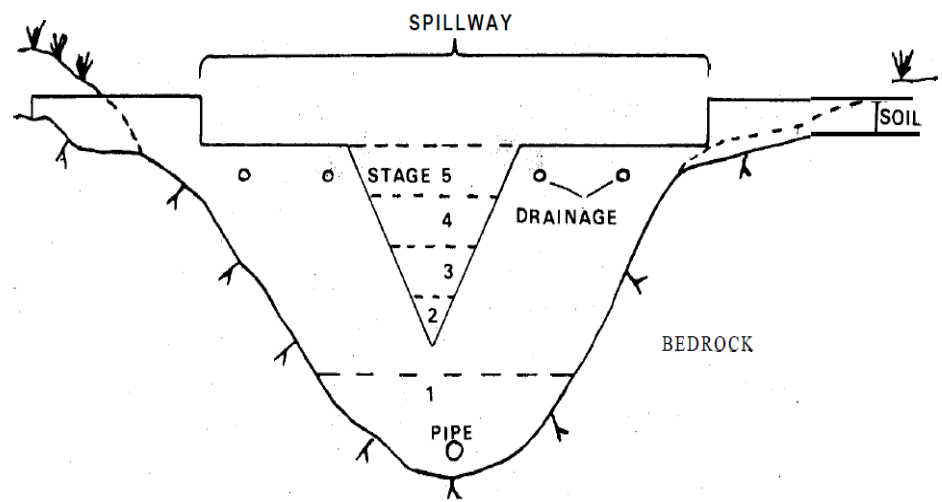
Nissen-Petersen, E., De Trincheria, J. (2015) [conference presentation]. How to get more water from sand dams –For half the cost. International Rainwater Harvesting and Resilience Symposium, Addis Ababa, Ethiopia, 1st-12th June 2015.

Restoration of SDs:

What to do with the thousands of silted-up SDs?

Restoring silted-up SDs

1. Through removal of previously accumulated sediments.
2. Hydraulic flushing coupled to dredging.
3. Accumulate new sand sediments by stages of reduced height.



Source: (Baurne, 1984)

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Rehabilitating SDs

- **Beneficial side-effects of silted-up SDs**:

  1. Reduction of the original slope of the riverbed → Lower erosion, higher retention of water.
  2. The foundations until the surface block the flow of shallow groundwater and increase water levels
  3. Sediments accumulated have agricultural potential.
  4. Failed infrastructure investment which can be redirected for cost-efficient activities other than water supply for local communities.

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Riverbed reclamation activities

- To practice agriculture and silvopasture on the riverbed.
- The agricultural potential of the sediments accumulated can be enhanced with smart-agroforestry and water and soil conservation techniques.

Source: (Studer and Liniger, 2013)

Pictures: Josep de Trincheria

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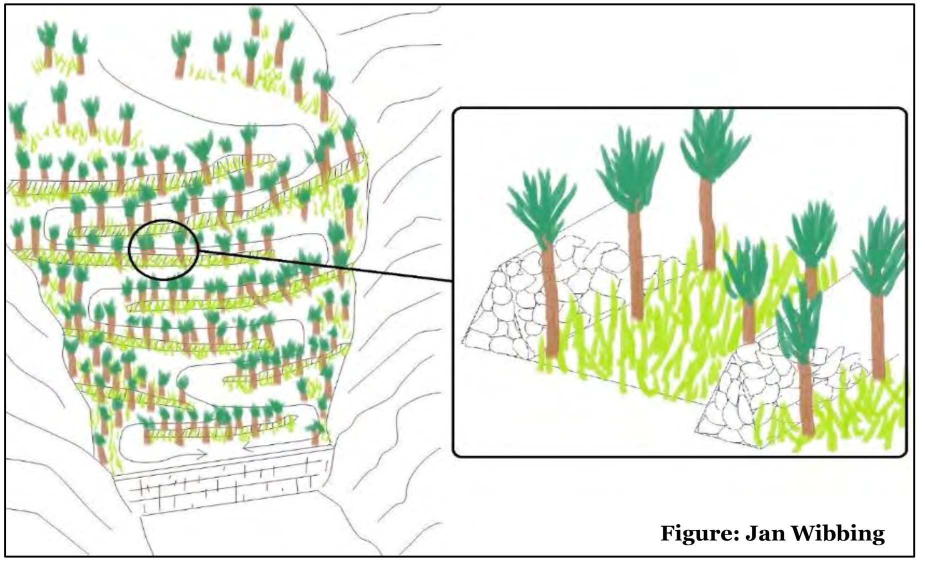
Enhancement of the agricultural potential

1. Deep rooting trees and grasses → To improve the percolation capacity.
2. Soil fertility increased with leguminous plants by the fixating nitrogen.
3. Plants resistant to drought and waterlogging.



4. Alternating rows of trees and grasses supported by stone walls can cause the runoff to meander.

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Rehabilitating SDs

- Riverbank agricultural reclamation activities → Silted-up SD is converted in a water spreading weir for spate irrigation.

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Thank you for your attention!

Further cooperation and research

We encourage implementing agencies to **contact us to scale up this research**!

→ Large-scale PME, restoring and rehabilitation programme on silted-up SDs.

Please, **send an email to:**
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Institute of Wastewater and Water Protection
Hamburg University of Technology, Germany
josepm.trinxeria@gmail.com

Discussion

What is limiting the implementation of a multi-stage construction process?

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Fostering the replication of smart sand storage dams in arid and semi-arid areas:

Practical recommendations to minimise siltation, seepage, evaporation and construction costs.

Advanced technical training course for practitioners

Kitui, Kenya

3rd February 2017

Josep de Trincheria

RUVIVAL Group

Hamburg University of Technology, Germany